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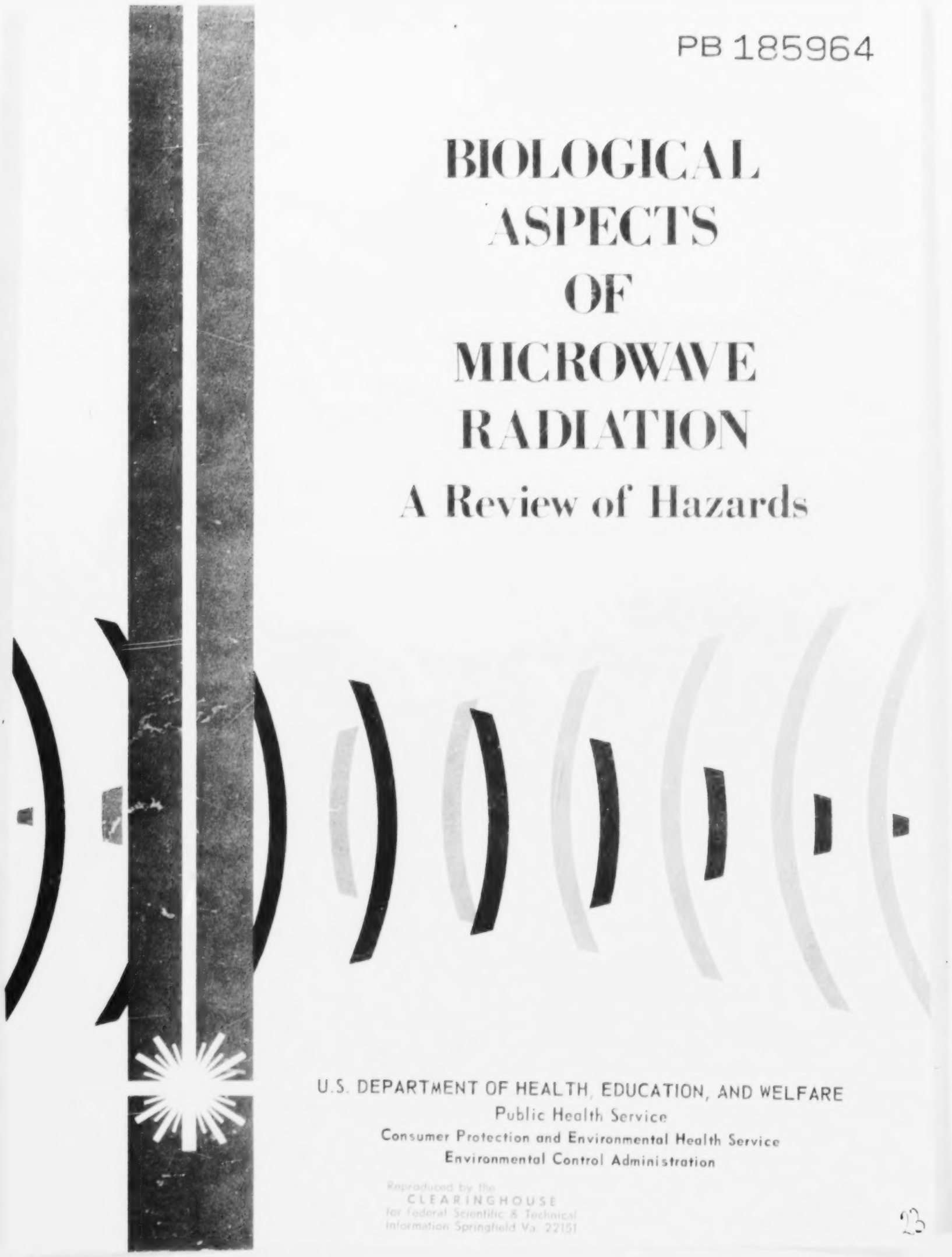
# BIOLOGICAL ASPECTS OF MICROWAVE RADIATION

## A Review of Hazards



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## A Review of Hazards

by

Wellington Moore, Jr., D.V.M., Ph.D.

July 1968

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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## FOREWORD

In addition to the widespread use for military and communications purposes, microwaves are finding increasing applications in industry, commerce, and most recently, in the home. This report briefly describes the principal uses of microwaves and presents information from a literature review pertaining to the nature of biological effects.

The report is intended as a guide for those concerned with the potential hazards of microwaves. The conclusions of a relatively large number of experiments and observations concerning biological effects are discussed. We hope that the information presented will be helpful in the development of standards for the protection of the public health.

D. J. Nelson, Jr.

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## INTRODUCTION

The widespread use of microwave generators for military, radio navigation, tracking, communications, food ovens, and other industrial purposes poses a potential hazard to the health of personnel concerned with their operation and to those who might be exposed in some manner to the energized beam. Microwave generators produce not only microwaves but also X-rays and small amounts of ultraviolet radiation which may constitute a local hazard. Modern high powered radars are capable of producing high power densities at appreciable distances from the sources. The potential hazards of these devices were recognized early in their development and concern for health hazards dates back to the early days of World War II, when Daily conducted his original studies on the U.S. Navy personnel engaged in the operation and testing of relatively low powered radar.[1] Although this study revealed no evidence of radar-induced pathology in human beings, somewhat later studies utilizing experimental animals revealed that cataracts, corneal opacities, testicular degeneration and hemorrhagic phenomena could be produced by exposure to microwaves.[2-4] During this period (1951), cataracts were first observed in a technician operating a microwave generator.[5] Several symposia have been held in recent years to discuss the various aspects of the potential hazards.[6-10] Evaluation of the experimental data led to the recommendation of a maximum safe exposure limit for whole body microwave radiation. The limit of 10 $mW/cm^2$ for the average power density for continuous exposure was adopted generally, although it is not a universally accepted standard. Sufficient data were not available to determine the safe exposure level for each frequency throughout the microwave range; therefore, one level was set for all frequencies. The following remarks are concerned with the nature of the biological effects and the regulations established for the maximum safe levels of exposure.

## NATURE OF MICROWAVES

Microwaves are electromagnetic radiations, intermediate in frequency and wavelength between conventional radio waves and far infrared waves. The approximate physical characteristics of this type of radiation are: (1) frequency, 30-300,000 megahertz; (2) wavelength, 1000-0.06 centimeters; (3) energy content, $10^{-7}$-$10^{-3}$ electron volts per photon. The

exact differentiation as to frequency and wavelength is a matter of definition and common usage. Existing radar systems utilize frequencies ranging from approximately 100 through 100,000 megahertz. Included also in the microwave range are frequencies used in television signal relay, long distance telephony, microwave ovens and electrotherapy. Frequencies of interest with respect to biological hazards are those lying between approximately 100 and 30,000 megahertz. Possible hazards at frequencies less than 100 MHz have not been adequately investigated.

The energy value per quantum is characteristic for each type of electromagnetic radiation, and is inversely related to the wavelength. Microwaves have comparatively low quantum energy; for example, one quantum of ultraviolet radiation of 2536 A° wavelength has 400,000 times as much energy as one quantum of 10 cm microwave radiation. The number of quanta for a given wavelength may be increased by increasing the flux density; however, the energy per quantum remains unchanged. Changes in molecular state depend upon the quantum energy of the radiation rather than on the number of those particular quanta. The energy values for microwaves are much too low to produce ionization as seen following X-ray and gamma radiation. The only transitions between energy levels in the molecular state that can be effected by microwaves are the extremely small transitions associated with heating and magnetic orientation.

Microwave radiation may be either the continuous wave type found in communication systems or the pulsed type utilized for radar installations, industrial and medical equipment. From a hazard standpoint, the pulsed energy may be considered of greater significance because of factors such as duty cycle, higher power density and energy distribution. On striking an object, microwaves may be transmitted, refracted, absorbed or any combination of these depending on the nature of the material interposed in the path of the radiation. When the target is a human being, determination of the portion of the incident energy that is absorbed is complicated by the inhomogeneity of the target, differences in sensitivity of organs and tissues, body mass in relation to the exposed area, and frequency of the microwaves.

## MODE OF ACTION ON BIOLOGICAL TISSUES

Although the exact nature of the biologic effects of microwave radiation is not completely understood, most of the experimental data support the concept that the effects are primarily due to local or general hyperthermia.[11,12] The heating effect of electromagnetic radiation on humans was first demonstrated in 1890 by D'Arsonval. Since that time, microwaves have been used in diathermy for heating tissues for therapeutic purposes. Most of the biological effects are probably the result of the conversion of electromagnetic energy into heat energy within the tissue itself. Since temperature is related directly to the rate and extent of molecular vibrations, a large part of this increase in temperature is

due to increased vibration of polar molecules.[13] Even though the overall electrical effect of a polar molecule is neutral, as in the case of water, the distribution of charge within the molecule is asymmetrical.[14] In an applied electrical field, the polar molecules tend to line up and vibrate. They oscillate (vibrate) with greater amplitude than normal thermal vibrations only if the field oscillates such as is the case with microwave radiation. It has been pointed out that heat generation (and microwave absorption) is greatest in those tissues with a high content of water and is also enhanced locally in the areas adjacent to bone or tough fascial planes which act as reflecting surfaces.[15-17]

The separation of thermal and non-thermal effects of the absorption of microwaves in biological systems is very difficult. Several investigators have pointed out the possibility that microwaves may interact with biological material without the production of a significant amount of heat. According to Russian workers, exposure of animals to microwaves of low intensity, which do not produce any appreciable thermal effect, leads to functional changes mainly in the nervous and cardiovascular systems (changes in excitation and inhibition relationships in cerebral cortex, change in rhythm of cardiac activity, nature of electrocardiogram, etc.).[18] Other reported non-thermal interactions include pearl chain formations,[19] mutations in exposed garlic root tips,[20] changes in paper electrophoretic pattern of human gamma globulin,[21] sounds heard by several people which correspond to the frequency of modulation of an incident microwave beam[22] and occasionally epigastric distress in humans.[23] Thus, there is evidence of biological interaction with electromagnetic fields in the absence of appreciable tissue heating (although it is still questionable whether some of these are unrelated to heating effects), but their clinical significance to man, if any, is not known.

## PHYSICAL FACTORS INFLUENCING TISSUE DAMAGE

The type of body tissues and the degree of damage effected by microwaves depend in general on the frequency of the radiation, the intensity of the beam, length of exposures, the dielectric constant, and thermal conductivity of the tissues. The percentage of absorbed energy and distribution of energy in the skin, fat and deep tissues are determined by the tissue dielectric properties which vary with the frequency.[24] The depth of penetration decreases with an increase in frequency (or decrease in wavelength). It has been postulated that the depth of penetration of microwaves in human tissues is on the order of 1/10 of the wavelength.[25] At frequencies less than 150 MHz, the body is transparent to the radiation with no appreciable absorption occurring. Between 150 and 1000 MHz, the energy is absorbed by the deeper tissues due to the penetration. From theoretical considerations and experiments on phantoms, it has been shown that the proportion of energy absorbed is approximately 40% of the incident energy arriving at the body surface for frequencies in this range. This energy range is potentially the most hazardous with respect

to whole body heating because there is little or no heating of the skin where thermal receptors would be stimulated. Radiation at frequencies between 1000 and 3000 MHz is subject to varying degrees of penetration and is absorbed in both superficial and deeper tissues depending upon tissue characteristics. The percentage of incident energy absorbed varies from approximately 20 to 100% because of tissue factors governing impedance values.[25] Absorption coefficients for body tissues depend on the water content. For example, skin, muscle and internal organs all have a high water content and high absorption coefficients; whereas, bone, fat, and yellow marrow have a low water content and low absorption coefficients. The eyes are most susceptible to frequencies around 3000 MHz where production of cataracts is an important consideration. For higher frequencies only superficial penetration occurs with heating of the tissues in much the same manner as for infrared radiation or direct sunlight. Except for the eyes, the sensation of warmth provides a warning mechanism for the individual exposed. The percentage of energy absorbed may approach 40% with the remaining portion being largely reflected.

In addition to frequency, the hazards potential of microwave radiation is dependent upon the intensity of the radiation and the length of exposure. The thermal response to microwave radiation is a function of the energy input or flux density. The fact that the amount of heating in tissues can be controlled by regulating the intensity and length of exposure forms the basis for the clinical use of microwave diathermy and the development of microwave ovens. The design of the antenna or reflector used in transmission affects the concentration of the energy and the potential hazard. The designs used in radar and diathermy concentrate the energy into a relatively small, narrow beam whereas those used in communications tend to disperse the beam so that the energy per unit of cross sectional area is exceedingly small. Also, in regard to radar exposure, the length of exposure is somewhat complicated because of the pulsed nature of the transmission. The importance of the length of time between exposures of pulsed microwaves has been demonstrated in animals. Deichmann[26] found that at 24,000 MHz and a power density of 300 $mW/cm^2$, a rat could be killed by receiving 16 minutes of actual exposure on a schedule of one minute of exposure and one minute of nonexposure in alternation. However, if an animal was given one minute of exposure followed by five minutes of nonexposure in alternation, it would take approximately 34 minutes of actual exposure to produce a lethal effect. The longer interval of time between exposures allowed for some adjustment by the heat regulatory mechanisms in the animal body and some dissipation of heat.

## WHOLE BODY EXPOSURE

When the whole body is subjected to microwave irradiation, the heat results from energy absorption must be dissipated by various means at the disposal of the body including radiation, conduction and evaporation

of perspiration. If the body cannot dissipate the heat energy as fast as it is produced, the temperature of the body will rise. The amount of heat the human body can transfer is, under normal circumstances, about 10 $mW/cm^2$.[11] This may be raised about tenfold under very favorable circumstances. From the standpoint of whole body heating, the frequencies between 150 and 1200 MHz are most important since most of the energy received is absorbed by and heats the deeper tissues.[27]

The problem of heat dissipation is complicated by the fact that for each degree of temperature rise above normal the basal metabolic rate increases by as much as 14%. This increase in basal metabolic rate demands an increase in the blood circulation and respiration, as well as a 50 to 100 percent increase in the supply of oxygen to the tissues to maintain cellular activity. The condition is aggravated by the reduced capability of hemoglobin to combine with oxygen and by the increased blood circulation rate, which reduces the time available for oxygen transfer in the lungs. During the rise in temperature, reactions indicative of a nonspecific pituitary-adrenal response to stress occur, including a sharp decrease in eosinophils and lymphocytes, and a rise in leukocytes.[28-30] Since the whole body will tolerate only a limited increase above normal temperature, an excessive rise in temperature due to microwave irradiation will produce tissue damage indistinguishable from that due to fever of any origin.[4,17,31,32] Pathological changes found at autopsy following death due to severe hyperpyrexia include diffuse degenerative changes throughout the body, myocardial degeneration and necrosis, hemorrhagic lesions in the gut, respiratory tract, liver and brain. Fatally exposed animals develop acidosis, hyperpnea, tetany, and finally die of respiratory arrest.

It is difficult to define safe exposure limit with respect to the production of hyperthermia resulting from whole body microwave irradiation. From the accumulated experimental data it becomes clear that each species differs in terms of relative sensitivity to whole body radiation. Thus it would be inaccurate to extrapolate to man from data obtained from animals; however, this information does provide guidelines. The great variability is due to many factors such as thickness and texture of the animals' hair coat and skin, the ratio of surface area to body mass, body size in relation to wavelength employed, etc. Also the mechanisms of thermoregulation and their efficiency vary in different species and in this respect man is perhaps the best protected of all animals. Human beings, for example, exposed to a flux of 0.22 $W/cm^2$ for 48 minutes showed a slight fall in rectal temperature due to the efficiency of the sweating mechanism in the dissipation of heat.[35] In contrast, rabbits can tolerate an indefinite exposure to a flux of 0.01 $W/cm^2$ with no rise in body temperature,[33] but show a $1^{\circ}$ C rise with a flux of only 0.02 $W/cm^2$ and some deaths from hyperthermia occur in two hours at a power density of 0.03 $W/cm^2$.[4,34,35] Ely and Goldman using 10-cm microwave radiation with a flux of 0.1 $W/cm^2$ produced lethal

fevers in rats, rabbits, and dogs.[35] Ely and Goldman postulated that the human could tolerate a higher flux than fur-bearing animals. They estimated that 100 $mW/cm^2$ would be required to maintain a human body temperature rise of 2° C.[35]

## CRITICAL ORGANS

Experimental evidence has established that certain organs (eyes, testicles, gall bladder, urinary bladder, and portions of the gastrointestinal tract) of the body are more susceptible than others to microwave radiation. This increased susceptibility is due to difference in the magnitude of blood flow which affects the rate of heat removal from these tissues during exposure. Experimental evidence indicates that the eyes and testicles are the most vulnerable to microwave radiation. Similarly in the case of localized irradiation of a single organ or tissue, the dissipation of heat is dependent chiefly upon the magnitude of blood flow through the part. A temperature rise resulting from moderate irradiation of the normal human arm or leg is self-limiting in that the temperature rise, which reaches a maximum in 10 to 20 minutes, is then reversed by a marked local increase in blood flow.[17] In relatively ischemic tissues, such as the eye and testes, continued irradiation can result in local temperature rises of as much as 10 to 20° C for a longer duration.[35,36,37]

### A. Eye

Within the critical wavelengths, the potential hazard to the eye is one of the most serious aspects of microwave exposure. In addition to the relatively poor blood supply, the cavities near the eye and high electrical conductivity of the intraocular fluids and the consequent short penetration of electromagnetic radiation in the eyeball (depth of penetration is approximately inversely proportional to the electrical conductivity within frequency and conductivity limitations) affect the eye's ability to conduct excessive heat to other parts of the body. The lens, being avascular and enclosed in a capsule, is at a disadvantage by not having a cooling system (vascular system) as other tissues. Not having available macrophages to remove dead cells or replacement cells, it cannot repair itself as occurs in reparative processes elsewhere in the body. Thus, damage to the lens is generally irreversible. Depending upon the dose, the damaged cells slowly lose their transparency and the opacity may not occur until sometime after exposure. Microwave irradiation may also produce damage to other ocular structures such as the conjunctiva, cornea, and iris.[38,39]

Microwaves have been shown to produce cataracts in a variety of experimental animals[2,3,36,37,38,40] and have also been implicated in the induction of cataracts in man following accidental exposure.[5,41-45] In

1952, Hirsch[5] reported the first case of cataract formation in a technician operating a microwave generator in the 1500 to 3000 MHz range, whose eyes were exposed in his daily work for approximately one year to a power density of 0.1 W/cm$^2$. The amounts of energy delivered to this man's eyes were in the order of hundreds of joules per square centimeter. Zaret[43] reported three cases of cataracts in individuals who had histories of repeated exposures to microwave radiation. All of the cases were discovered after a time lapse and the power densities were retrospectively estimated to have ranges from 350 mW/cm$^2$ to several Watts/cm$^2$. A crude relation between the power density of microwave radiation delivered to the eye and the time of occurrence of cataract formation was established. Where the lens was believed to be exposed repeatedly to 5 W/cm$^2$, the cataract was fully formed in two months. Where the lens was believed to be exposed repeatedly to 500 mW/cm$^2$, many months passed before early opacifications appeared and many years passed before the cataract was fully formed. In addition to these three cases, Zaret has reported several other cases which are discussed in another section of this paper.

There is some disagreement as to the lowest effective intensity required to produce cataracts in experimental animals. It has been established that a power density of 0.1 W/cm$^2$ applied directly to the eye can be tolerated for hours at a time with no production of cataracts.[34,35,36,44] Carpenter[44,45] stated that a 10 minute exposure at 0.28 W/cm$^2$ will cause opacities while Ely, et al., indicated that an indefinite exposure at a density of 0.2 W/cm$^2$ does not cause any damage. Williams, et al.,[36] demonstrated cataract formation with a single exposure of 5 minutes at 0.59 W/cm$^2$, 20 minutes at 0.40 W/cm$^2$, 40 minutes at 0.32 W/cm$^2$, and 90 minutes at 0.29 W/cm$^2$. Vitreous temperatures between 53° and 49° C, respectively, were characteristic of threshold exposures between 5 to 25 minutes duration. The level represents a 10° to 14° elevation of vitreous temperature above normal and agrees well with the range of 51° to 55° C which was found significant in opacity production by Richardson.[46] Damage to the eye is especially pronounced at wavelengths around 12 cm.[47] Temperature graphs give the location of the temperature maximum for this wavelength (12 cm) near the center of the eye.

Carpenter[44,45] has presented evidence that pulsed radar waves with a high peak power are more effective in producing cataracts in the rabbit's eye than continuous output of the same average power. A single 20 minute exposure to radar (frequency, 2500 MHz) on a 50% duty cycle, with a peak power of 0.28 W/cm$^2$ (equivalent to continuous power of 0.14 W/cm$^2$) produces opacities in 8 out of 12 rabbits, while a 20 minute exposure to continuous power of 0.14 W/cm$^2$ did not produce opacities.

An important practical question, on which there are conflicting opinions, concerns the possibility of cumulative damage to the lens from repeated

subthreshold irradiation. Most investigators agree that there is a critical intraocular temperature which must be reached before opacities develop. This temperature, as reported by various authors, ranges from 45 to 55° C. Obviously no cumulative rise in temperature can occur if the intervals between exposure exceed the time required for the tissue to return to normal temperature. The cumulative effect to be anticipated, therefore, is the accumulation of damage resulting from repeated exposures, each of which is individually capable of producing some degree of damage. However, Carpenter[45] states that if the eye is subjected to repeated subthreshold exposures cataracts may develop with the time interval between successive exposures being the most important factor in the production of a cumulative effect. Cleary, et al.,[48,49] found that although repeated subthreshold exposure may produce minimal types of lens changes, it does not appear to increase the incidence of cataracts in Army and Air Force personnel following occupational exposure.

B. Testicles

The testicles are extremely sensitive to elevations in temperature. It has been found, as in cases of undescended testes, that spermatogenesis can take place only at temperatures below that of the body core. Normal human testicular temperatures average 2° C (3.6° F) below body temperature although this varies from individual to individual and varies in the same individual from time to time depending upon age and environment.[12] Of the various organs studied, the testes appear to be the most sensitive in terms of the minimum exposure required to produce a minimal change (reduction in spermatocytes and damage to cells lining the seminiferous tubules). In a study utilizing dogs, rabbits, and rats, Ely, et al.,[35] tried to determine the threshold value in terms of the lowest power density required to produce a minimal change in the most sensitive animal in the group. For this criterion, an exposure rate of 0.01 $W/cm^2$ was considered the threshold for testicular damage, on an indefinite exposure. It should be noted that the threshold for testicular damage in this study, 0.01 $W/cm^2$, is the same power density as the generally accepted exposure guideline. However, the authors stressed that the damage observed at such low levels of power is slight, almost certainly fully recoverable, and in no way different from that due to other common forms of heat that might be applied to the testes. Others have found evidence of testicular damage in rabbits when the testicular temperature was raised to 35° C.[50]

The pathological changes found in the testes include a degeneration of the epithelium lining the seminiferous tubules, and a sharp reduction in the numbers of maturing spermatocytes in the lumen.[35,50,51] The distribution of damage is irregular with adjacent tubules often showing markedly different degrees of degeneration. The reduction in testicular function due to heating appears to be temporary and is probably

reversible except in severe cases. Because of the paucity of information, any statement concerning the genetic implications of microwave radiation would be premature.

A general resume of the biological effects of microwaves is given in Table 1.

CUMULATIVE EFFECTS

An important consideration in the control of microwave hazards is the possibility of cumulative damage resulting from repeated exposure. Experimental data in this area of whole body radiation is limited and the observations are influenced by the exposure characteristics and by species differences. Prausnitz and Susskind[52] studied the pathological and longevity effects of chronic whole body exposure on 200 male mice. These animals were exposed daily for 59 weeks to 0.10 $W/cm^2$ (9270 MHz) for 4.5 minutes. The treatment produced an average body temperature rise of $3.3^{o}$ C. No significant differences were found in body weight, hemogram or longevity. Increased incidence of testicular degeneration and neoplasms of the white blood cells were observed. In another study two female beagle dogs were exposed to microwave radiation of 24,000 MHz at a power density of 20 $mW/cm^2$.[53] Over a period of 20 months one dog was exposed for a total of 2631 hours (6.7 hours per day on 5 days of the week) and the other dog was exposed for a total of 3970 hours (16.5 hours per day on 4 days of the week). No significant changes were found in the parameters (hemogram, blood chemistry, eyes) studied with the exception of subnormal body weight. Both animals reproduced normally although one or more "stillborns" occurred in each litter. The data obtained on man is based on microwave exposure situations where the amount of the body exposed, field intensities, and duration of exposure cannot be accurately determined. Daily[1] conducted the first studies on United States Navy personnel who were exposed over a period of time in the operation and testing of relatively low powered radar. No evidence of radar-induced pathology was found. Lidman and Cohn[54] examined the blood of 124 men who had been exposed to microwaves for periods from 2 to 36 months. They concluded there was no evidence of stimulation or depression of the erythropoietic or leukocytic systems of these men. In another study a large group of radar exposed employees, along with a control group, was put under a four-year surveillance program.[55] During this period they underwent repeated physical, eye, hematological and other laboratory examinations. These examinations failed to detect any significant changes. Fertility studies revealed essentially the same findings for both groups. Zaret[41] conducted an extensive study of the frequency of occurrence of lenticular imperfections in the eyes of a sample of 736 microwave workers and a control sample of 559 individuals engaged in installation, operation and development of microwave equipment. The exposure ranged from a few days to almost 18 years with a wide range of frequencies and power outputs varying from

Table 1

Resume of Biological Effects of Microwaves

| Frequency MHz | Wavelength (cm) | Site of Major Tissue Effects | Major Biological Effects |
|---|---|---|---|
| Less than 150 | Above 200 | | Body is transparent to waves above 200 cm. |
| 150 - 1,200 | 200 - 25 | Internal body organs | Damage to internal organs from overheating |
| 1,000 - 3,300 | 30 - 10 | Lens of the eye | Lens of the eye particularly susceptible and tissue heating |
| 3,300 - 10,000 | 10 - 3 | Top layers of the skin, lens of the eye | Skin heating with the sensation of warmth |
| Above 10,000 | Less than 3 | Skin | Skin surface acts as reflector or absorber with heating effects |

less than a watt to several kilowatts. No late lens defects were found to be peculiar to microwaves. Significant increases in the occurrence of lens defects were found in the exposed groups as compared to the control group. This study further concluded that the extent of minor lenticular imperfections does not serve as a clinically useful indicator of cumulative exposure to microwave radiation.

As of May 1967, Zaret has reported 26 new cases of lenticular damage from microwaves.[56] In contrast to the experimental data available in the United States, Russian and Polish investigators have reported a large number of general effects in humans due to chronic exposure to UHF and microwaves.[57,58] The general effects of chronic exposure include bradycardia, hypotension, hyperthyroidism, central nervous system exhaustion, decrease in the sense of smell, increased histamine level in the blood, lenticular changes and changes in intraocular pressure. The effects tended to vary with the intensity of the radiation. The significance of this discrepancy between experimental results remains to be determined. Also a major drawback of the human studies which especially illustrates the need for further research is the limited sample size on which the findings are based. The numbers of people observed are miniscule so far as epidemiologic surveys go. The only human epidemiologic evidence to date, for possible genetic damage as a result of microwave exposure, is in the study of Sigler, et al.[59] There was an increased incidence of Mongolism in children of fathers having prior exposure to radar.

## MAXIMUM PERMISSIBLE EXPOSURE LEVELS

In the development and use of microwave equipment, a major concern of both military and civilian authorities was the establishment of safe limits of exposure for personnel engaged in their operation. In 1953, Schwan recommended that microwave radiation of 10 $mW/cm^2$ be accepted as a tolerance dose. Subsequently after a review of all the experimental data on animal exposures available at that time, it became apparent that an exposure to a power density of approximately 0.1 $W/cm^2$ was necessary in order to produce any effect of biological significance. Whole body or localized exposure at this power density had been shown to produce either hyperthermia or damage to organs such as the eyes or testes. Because of the uncertainties concerning the possible effects of certain variables, it was decided to include a safety factor of ten in the proposed safe level. On this basis a maximum safe exposure level of 10 $mW/cm^2$ was promulgated. This level was to be interpreted in terms of the ambient energy level without reference to frequency or duration of exposure. The value was accepted generally and formed the basis for working levels in industry and the armed services. Table 2 presents the maximum permissible intensities reported for several countries. Attention is called to the very stringent exposure levels for certain countries. These values range from 100 to 1000 fold less than those used in the United States.

Table 2

Maximum Permissible Intensities

| Institution or Country | Frequency MHz | Maximum Permissible Intensity in $mW/cm^2$ | Remarks |
|---|---|---|---|
| U.S.S.R. (1958)[58] | 300 - 30,000 | 0.01<br>0.1<br>1 | Whole working day<br>2 - 3 hours daily<br>15 - 20 minutes daily |
| Poland (1961)[57] | Over 300 | 0.01<br>0.1<br>1 | Whole working day<br>2 - 3 hours daily<br>15 - 20 minutes daily |
| Post Office of Great Britain (1960)[60] | 30 - 30,000 | 10 | Continuous daily exposure in case of pulsed waves, an average over the complete train of pulses |
| U.S. Army and Air Force (1965)[23] | - | 10 | Maximum permissible level for continuous exposure |
| | - | 10 - 100 | limited occupancy exposure time (minutes = $\frac{6000}{(X mW/cm^2)^2}$ |
| | - | Over 100 | Denied occupancy |
| U.S. Standards Institute[61] C95.1 - 1966 | - | 10<br>1 mW hr/$cm^2$ | For periods of 0.1 hours or more<br>during any 0.1 hour period |

Recently the United States Army and Air Force and the C-95 Committee of the United States of America Standards Institute have adopted new standards which equate the power density to the length of exposure. This new standard permits exposure to levels greater than 10 $mW/cm^2$ for a given interval of time. This revision of the standard to allow exposure to higher power density levels became necessary because of the increased power output of newer microwave systems. The Standards Institute regulations allow exposures up to 1 $mW/cm^2$ for any 0.1 hour period. For example, if a worker is exposed for 0.1 hour (six minutes) during a one-hour period, he may receive 10 $mW/cm^2$; if he is exposed for 0.01 hour (36 seconds) during a one-hour period, he may receive 100 $mW/cm^2$. For periods of 0.1 hour or more the level is 10 $mW/cm^2$. The Army-Air Force regulations permit exposures exceeding 10 $mW/cm^2$ based on the following equation:

$$T_P = \frac{6000}{W^2}$$

where:

$T_P$ = permissible exposure time in minutes during any one-hour period

$W$ = power density in the area to be occupied ($mW/cm^2$)

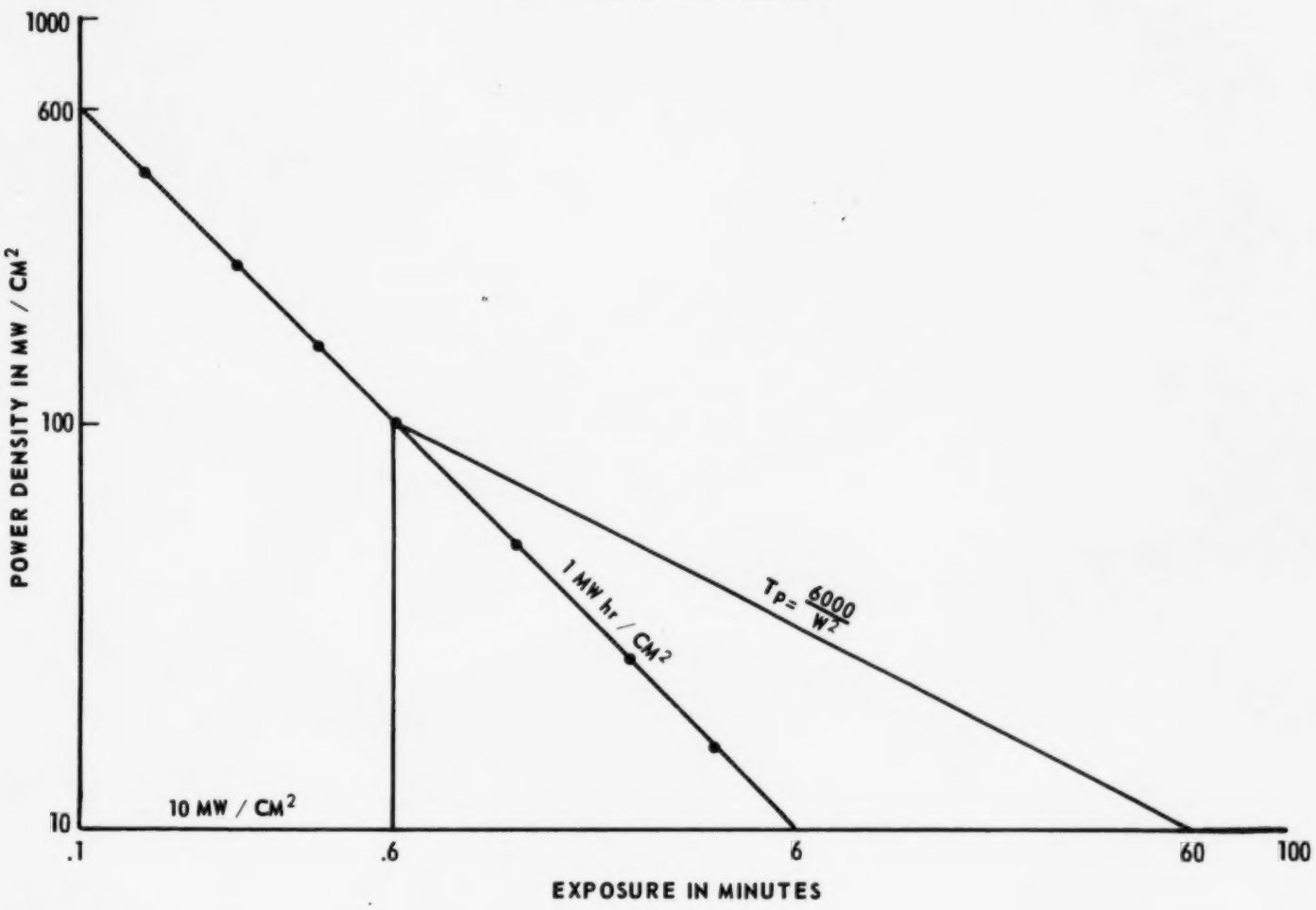
The Standards Institute specified no upper limit for the power density whereas the military standards prohibit any exposure over 100 $mW/cm^2$. Figure 1 shows exposure in minutes versus power density for the standard of 10 $mW/cm^2$, the Standards Institute 1 $mW\ hr/cm^2$, and the military $\frac{6000}{W^2}$. For a single discrete exposure, the Standards Institute would be more conservative for levels below 100 $mW/cm^2$ and less conservative for levels above 100 $mW/cm^2$ where the military permit no exposure. The two are in agreement at 100 $mW/cm^2$ and have their greatest divergence at six minutes where the exposure the Standards Institute would allow is 10 $mW/cm^2$ and the military 32 $mW/cm^2$.

## DISCUSSION AND CONCLUSION

Microwave systems have become a part of our way of life and exposure is not limited to military personnel, nor persons engaged in the fabrication of this equipment. Besides communications and navigational uses, microwaves have been utilized in a variety of commercial processes that require heating and drying, such as drying of photographic film, potato chips, and glue binders in plywood. Probably the greatest area of advancement is in the use of microwave heating in food preparation. Microwave ovens are popular in commercial restaurants, self-service food vending establishments, and now are available for home use. Some

Figure 1

EXPOSURE vs POWER DENSITY[12]



estimates put the microwave oven purchases as 25% of all ovens bought in the United States by 1976, or approximately 1.8 million ovens.[62] Although the magnitude of the potential hazard of microwave ovens is less, many operators of these units are not aware of the potential health hazards, and precautionary labels are not displayed on the ovens to warn the operators.[63]

Although the biological effects of microwaves have been studied, certain areas, such as the possibility of cumulative effects from subthreshold exposures, functional changes from low intensity irradiation as reported by the Russians and possible nonthermal changes need further clarification. Large gaps also exist in the current knowledge of possible genetic implications and the actual long-term effects, if any, of microwave radiation on humans.

## REFERENCES


1. Daily, L. E.: Clinical Study of Results of Exposure of Laboratory Personnel to Radar and High Frequency Radio. U.S. Nav. M. Bull., 41:1052 (1943).

2. Daily, L., Jr., K. G. Wakim, J. P. Herrick, and E. M. Parkhill: Effects of Microwave Diathermy on the Eye. Amer. J. Physiol., 155:432 (1948).

3. Richardson, A. W., T. D. Duane, and H. M. Hines: Experimental Lenticular Opacities Produced by Microwave Irradiations. Arch. Phys. Med., 29:765-769 (1948).

4. Boysen, J. E.: Hyperthermic and Pathologic Effects of Electromagnetic Radiation (350 Mc). A.M.A. Arch. Indust. Hyg., 7:516-525 (1953).

5. Hirsch, F. G., and J. T. Parker: Bilateral Lenticular Opacities Occurring in a Technician Operating a Microwave Generator. A.M.A. Arch. Indust. Hyg., 6:512-517 (1952).

6. Pattishall, E. G.: Proceedings of Tri-Service Conference on Biological Hazards of Microwave Radiation. ARDC-TR-58-51, University of Virginia (1957).

7. Pattishall, E. G., and F. W. Banghart: Proceedings of Second Tri-Service Conference on Biological Effects of Microwave Energy. University of Virginia, ASTIA Doc. No. AD-131-477 (1958).

8. Mayo Clinic and Mayo Foundation, Symposium on Physiological and Pathological Effects of Microwaves. I.R.E. Trans., Med. Electron., ME-4:Feb. 1956.

9. Susskind, C.: Proceedings of the Third Annual Tri-Service Conference on Biological Effects of Microwave Radiating Equipment. University of California, Berkeley, Calif. (1959).

10. Peyton, M. F.: Proceedings of the Fourth Annual Tri-Service Conference on the Biological Effects of Microwave Radiation. Plenum Press, N.Y. (1961).

11. Schwan, H. P., and G. M. Piersol: The Absorption of Electromagnetic Energy in Body Tissues. A Review and Critical Analysis. Part II, Physiologic and Clinical Aspects. Amer. J. Phys. Med., 34:425-448 (1955).

12. Palmisano, W. A., and A. Peczenik: Some Considerations of Microwave Hazards. Exposure Criteria. Part I, Biological Effects Mil. Med., 131:611-618 (1966).

13. White, H. E.: Modern College Physics. D. Van Nostrand Co., Princeton, N.J., 271 (1956).

14. Hogness, T. R., and W. C. Johnson: Qualitative Analysis and Chemical Equilibrium. Henry Holt Co., N.Y., 36 (1940).

15. Schwan, H. P.: Alternating Current Spectroscopy of Biological Substances. Proc. IRE, 47:1841-1855 (1959).

16. Schwan, H. P.: The Biophysics of Diathermy Therapeutic Heat. Elizabeth Licht, New Haven, Conn., 55 (1958).

17. Herrick, J. F., and F. H. Krusen: Certain Physiologic and Pathologic Effects of Microwaves. Electrical Eng., 72:239-244 (1953).

18. Gordon, Z. V.: Problem of the Biological Action of UHF. U.S. Joint Pub. Res. Service, 12471:1-4 (1962).

19. Sher, L. D., and H. P. Schwan: Mechanical Effects of A.C. Fields on Particles Dispersed in a Liquid: Biological Implications. O.N.R. Tech-Report No. 37, Electromedical Division, The Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia (1963).

20. Heller, J. H., and A. A. Teixeira-Pinto: A New Physical Method for Creating Chromosomal Aberrations. Nature, 183:905-906 (1959).

21. Bach, S. A., A. J. Luzzio, and A. S. Brownell: Effects of Radio-Frequency Energy on Human Gamma Globulin. Proceedings of the Fourth Annual Tri-Service Conference on Biological Effects of Microwave Radiation, 1:117-133 (1961).

22. Frey, A. H.: Human Auditory System Response to Modulated Electromagnetic Energy. J. Appl. Physiol., 17:689-692 (1962).

23. Control of Hazards to Health from Microwave Radiation. Dept. of Army and Air Force, TB Med. 270 (1965).

24. Schwan, H. P., and K. Li: The Mechanism of Absorption of Ultrahigh Frequency Electromagnetic Energy in Tissues, as Related to the Problem of Tolerance Dosage. I.R.E. Trans. Med. Electron., ME-4:45 (1956).

25. Vogelman, J. H.: Physical and Electrical Characteristics of a Microwave Hazard. Twelfth Annual Conference on Electrical Techniques in Medicine and Biology. Digest of Technical Papers. RADC, TR-59-227.

26. Deichmann, W. B., M. Keplinger, and E. Bernal: Relation of Interrupted Pulsed Microwaves to Biological Hazards. RADC, TR-59-140:77 (1959).

27. MacMurray, L. C., E. J. Dehne, and R. H. Duguid: Health Hazards Associated with Microwave Radiation. U.S. Army Environmental Hygiene Agency. Technical Publications, April 1958.

28. Adler, E., and A. Magora: Experiments on the Relation Between Short Wave Irradiation and the Pituitary-Cortical-Adrenal System. Amer. J. Phys. Med., 34:521-534 (1955).

29. Howland, J. W., R. A. E. Thomson, and S. M. Michaelson: Biomedical Aspects of Microwave Irradiation of Mammals. In: Biological Effects of Microwave Radiation, Plenum Press, N.Y., Vol. 1:261 (1960).

30. McLaughlin, J. T.: Health Hazards from Microwave Radiation. Western Medicine, 3:126-131 (1962).

31. Hartman, F. W.: The Pathology of Hyperpyrexia. In: Proceedings of the Second Tri-Service Conference on Biological Effects of Microwave Energy. ASTIA Doc. No. AD-131-477. U.S.A.F., Rome, N.Y., 54-69 (1958).

32. Oldendorf, W. H.: Focal Neurological Lesions Produced by Microwave Irradiation. Proc. Soc. Exp. Biol. Med., 72:432-434 (1949).

33. Schwan, H. P., and K. Li: Hazards Due to Total Body Irradiation by Radar. Proc. I.R.E., 44:1572-1581 (1956).

34. Cogan, D. G.: A.M.A. Arch. Indust. Hlth., 18:299 (1958).

35. Ely, T. S., and D. E. Goldman: Heating Characteristics of Laboratory Animals Exposed to Ten-Centimeter Microwaves. In: Proceedings of Tri-Service Conference on Biological Hazards of Microwave Radiation. ARDC-TR-58-51. E. G. Pattishall, ed. University of Virginia, 1957, pp. 64-75.

36. Williams, D. B.,J. P. Monahan, W. J. Nicholson, and J. J. Aldrich: Biologic Effects Studies on Microwave Radiation. Time and Power Thresholds for Production of Lens Opacities by 12.3 cm Microwaves. A.M.A. Arch. Ophth., 54:863-874 (1955).

37. Daily, L., Jr., E. A. Zeller, K. G. Walkim, J. F. Herrick, and W. L. Benedict: Influence of Microwaves Upon Certain Enzyme Systems in the Lens. Amer. J. Ophth., 34:1301-1306 (1951).

38. Seth, H. S., and S. M. Michaelson: Microwave Cataractogenesis. J. Occup. Med., 7(9):439-443 (1965).

39. Seth, H. S., and S. M. Michaelson: Microwave Hazards Evaluation. Aerospace Med., 15:734-739 (1964).

40. Van Ummersen, C. A., and F. C. Cogan: Experimental Microwave Cataracts. Age as Factor in Induction of Cataracts in the Rabbit. Arch. Environ. Health, 11:177-178 (1965).

41. Zaret, M. M., and M. Eisenbud: Preliminary Results of Studies of the Lenticular Effects of Microwaves Among Exposed Personnel. In: Proceedings of the Fourth Annual Tri-Service Conference on the Biological Effects of Microwave Radiation. Plenum Press, N.Y., Vol. 1:293-308 (1961).

42. Zaret, M. M.: The Biological Effects of Microwave Radiation. Indust. Hyg. Review, 5:11-13 (1962).

43. Zaret, M. M.: An Experimental Study of the Cataractogenic Effects of Microwave Radiation. Technical Documentary Report No. RADC-TDR-64-273. Rome Air Development Center, Griffiss AFB, N.Y. (1964).

44. Carpenter, R. L.: Review of the Work Conducted at Tufts University. Experimental Radiation Cataracts Induced by Microwave Radiation. In: Proceedings of the Second Tri-Service Conference on Biological Effects of Microwave Energy. University of Virginia, ASTIA Doc. No. AD-131-477, pp. 146-168 (1958).

45. Carpenter, R. L.: An Experimental Study of the Biological Effects of Microwave Radiation in Relation to the Eye. RADC-TDR-62-131 (1962).

46. Richardson, A. W., T. D. Duane, and H. M. Hines: Experimental Cataract Produced by Three-Centimeter Pulsed Microwave Irradiations. A.M.A. Arch. Ophth., 45:382-386 (1951).

47. Cogan, D. G.: Lesions of the Eye from Radiant Energy. J.A.M.A., 142:145-151 (1950).

48. Cleary, S. F., B. S. Pasternack, and C. W. Bube: Cataract Medicine in Radar Workers. Arch. Environ. Hlth., 11:179 (1965).

49. Cleary, S. F., and B. S. Pasternack: Lenticular Changes in Microwave Workers. Arch. Environ. Hlth., 12:23-29 (1966).

50. Imig, C. J., J. D. Thomson, and H. M. Hines: Testicular Degeneration as a Result of Microwave Irradiation. Proc. Soc. Exper. Biol. Med., 69:382-386 (1948).

51. Clark, J. W.: Effects of Intense Microwave Radiation on Living Organisms. Proc. I.R.E., 38:1028-1032 (1950).

52. Prausnitz, S., and C. Susskind: Effects of Chronic Microwave Irradiation on Mice. I.R.E. Trans. on Biomedical Electronics, 104 (1962).

53. Deichmann, W. B., E. Bernal, F. Stephens, and K. Landeen: Effect on Dogs of Chronic Exposure to Microwave Radiation. J. Occup. Med., 5:418-425 (1963).

54. Lidman, B. I., and C. Cohn: Effect of Radar Emanations on the Hematopoietic System. Air Surgeon's Bull., 2:448-449 (1945).

55. Barron, C. I., and A. A. Baraff: Medical Considerations of Exposure to Microwaves (Radar). J.A.M.A., 168:1194-1199 (1958).

56. Zaret, M. M.: Chap. 2, Laser and Microwave Hazards Course Manual, U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, Md.

57. Letavet, A. A., and Z. V. Gordon: The Biological Action of Ultra-high Frequencies. U.S. Joint Publications Research Service, 12471 (1962).

58. Minecki, L.: Critical Evaluation of Maximum Permissible Levels of Microwave Radiation. Arch. Hyg. Rada., 15:47-55 (1964).

59. Sigler, A. T., A. M. Lilienfeld, B. H. Cohen, and J. E. Westlake: Radiation Exposure in Parents of Children with Mongolism (Down's Syndrome). Bull. Johns Hopkins Hospital, 117:374-399 (1965).

60. Safety Precautions Relating to Intense Radio-Frequency Radiation. The British Post Office. 25822 Wt. 2006-37290 K24 4/60, C.P. Ltd. 999/226, London.

61. Safety Level of Electromagnetic Radiation with Respect to Personnel (ASA C95.1-1966). U.S.A. Standards Institute C95.1 (1966).

62. Lasers and Microwave Hazards Course Manual. U.S. Army Environmental Hygiene Agency, Edgewood Arsenal, Md.

63. Suroviec, H. J.: Microwave Oven Radiation Hazards in Food Vending Establishments. Arch. Environ. Hlth., 14:469-472 (1967).

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